Transfer Functions for Direct Volume Rendering

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Contributions:
Many, as noted

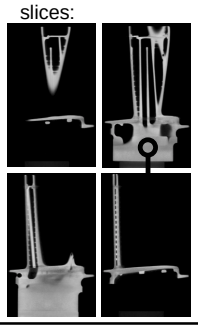
Outline

1. Transfer Functions: what and why
1. Review of current methods
2. Ideas for future work

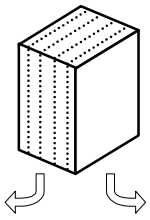
Introduction

Transfer functions make volume data visible by mapping data values to optical properties

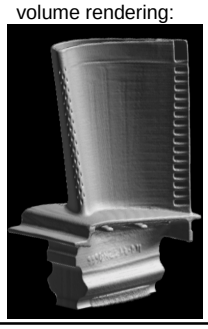
slices:



volume data:



volume rendering:

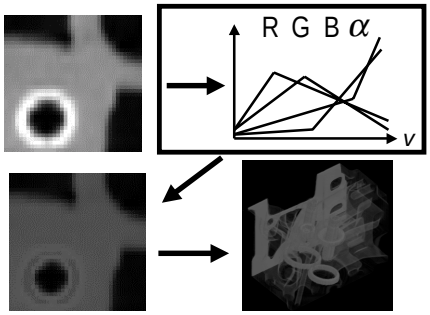


Optical Properties

Anything that can be composited with a standard graphics operator ("over")

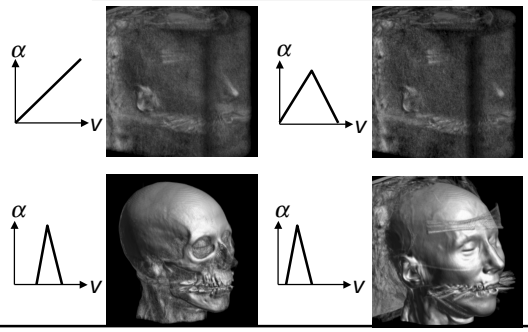
- Opacity: "opacity functions"
  - Most important
- Color
  - Can help distinguish features
- Emittance
  - Why don't we use this more often?
- Phong parameters (k_a, k_d, k_s)
- Index of refraction

TFs in action



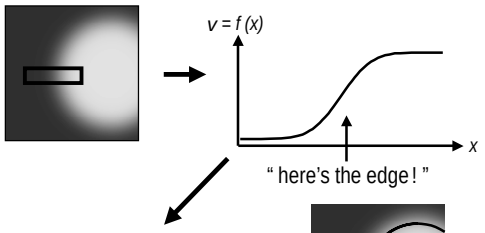
Alas…

Setting transfer functions is difficult, unintuitive, and slow

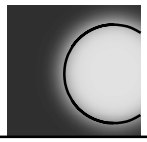


TFs as feature detection

Where's the edge?

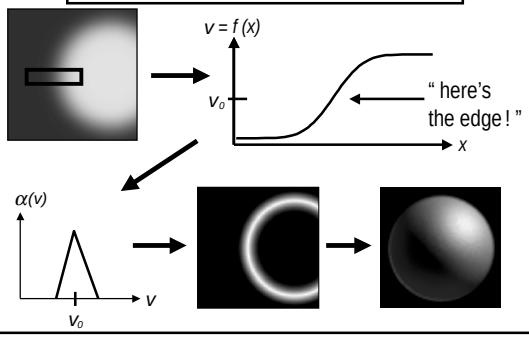


Result is set of edge pixels:



TFs as feature detection

We are looking in the data value domain, not the spatial domain



The goal

- Make space of TFs less confusing
- Make good renderings easier to come by
- Remove excess "flexibility"
- Provide one or more of:
  - Information
  - Guidance
  - Semi-automation
  - Automation

Outline

1. Transfer Functions: what and why

2. Review of current methods

3. Ideas for future work

Organization

1. Trial and Error (manual)
2. Spatial Feature Detection
3. Image-Centric
4. Data-Centric
5. Others

1. Trial and Error

1. Manually edit graph of transfer function
2. Enforces learning by experience
3. Get better with practice
4. Can make terrific images

William Schroeder, Lisa Sobierajski Avila, and Ken Martin; Transfer Function Bake-off Vis '00

2. Spatial Feature Detection

Transform TF specification to feature detection in the spatial domain

- extremely flexible
- different parameter space
- not exactly transfer functions …

1. Fang, Biddlecome, Tuceryan (Vis '98) "Image-based Transfer Function Design…"
2. Rheingans, Ebert (Vis '00, TVCG July '01) "Volume Illustration: Non-photorealistic…"
3. Hladůvka, Gröller (VisSym '01) "Salient Representation of Volume Data"

3. Image-centric

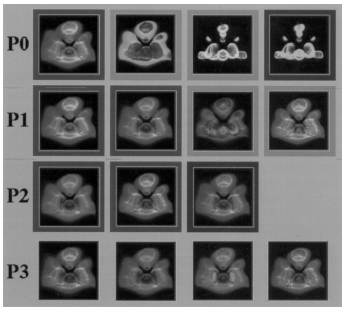
Specify TFs via the resulting renderings

- Genetic Algorithms ("Generation of Transfer Functions with Stochastic Search Techniques", He, Hong, *et al.*: Vis '96)
- Design Galleries (Marks, Andalman, Beardsley, *et al.*: SIGGRAPH '97; Pfister: Transfer Function Bake-off Vis '00)
- Thumbnail Graphs + Spreadsheets ("A Graph Based Interface…", Patten, Ma: Graphics Interface '98; "Image Graphs…", Ma: Vis '99; Spreadsheets for Vis: Vis '00, TVCG July '01)
- Thumbnail Parameterization ("Mastering Transfer Function Specification Using VolumePro Technology", König, Gröller: Spring Conference on Computer Graphics '01)

Genetic Algorithms

Initial stochastic search; refinement can be user driven or automated ("fitness functions")

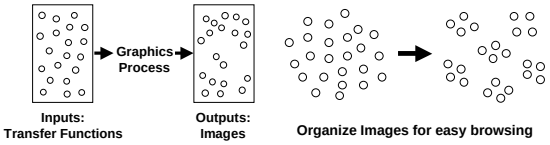
"Generation of Transfer Functions with Stochastic Search Techniques", He, Hong, *et al.*: Vis '96



Design Galleries

Effective method for general class of "parameter tweaking" problems

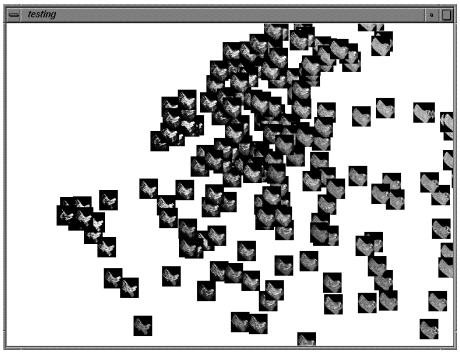
- Provide convenient GUI to whole parameter space ("what's possible?")
- Sampling parameter space: dispersion
- Organize output images: arrangement



Design Galleries

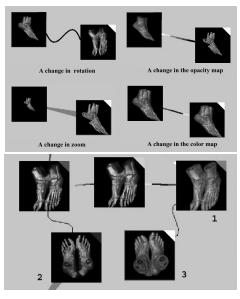
VolDG (software available)

Marks, Andalman, Beardsley, *et al.*: SIGGRAPH '97; Pfister: Transfer Function Bake-off Vis '00

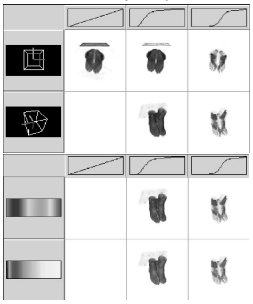


Thumbnail Graphs, Spreadsheets

Exploration guided by logically connected visual history or spreadsheet



"A Graph Based Interface for Representing Volume Visualization Results", Patten, Ma: Graphics Interface '98



"Visualization Exploration and Encapsulation via a Spreadsheet-Like Interface", Jankun-Kelly, Ma: TVCG July 2001

Thumbnail Parameterization

"Mastering Transfer Function Specification Using VolumePro Technology", König, Gröller: Spring Conference on Computer Graphics '01

4. Data-centric

Specify TF by analyzing volume data itself

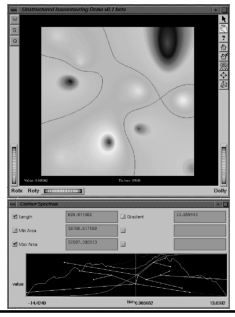
1. Salient Isovalues:
   - Contour Spectrum (Bajaj, Pascucci, Schikore: Vis '97)
   - Statistical Signatures ("Salient Iso-Surface Detection Through Model-Independent Statistical Signatures", Tenginaki, Lee, Machiraju: Vis '01)
   - Other metrics ("Fast Detection of Meaningful Isosurfaces for Volume Data Visualization", Pekar, Wiemker, Hempel: Vis '01)
2. "Semi-Automatic Generation of TFs …" (Kindlmann, Durkin: VolVis '98; Kindlmann MS Thesis '99)

Salient Isovalues

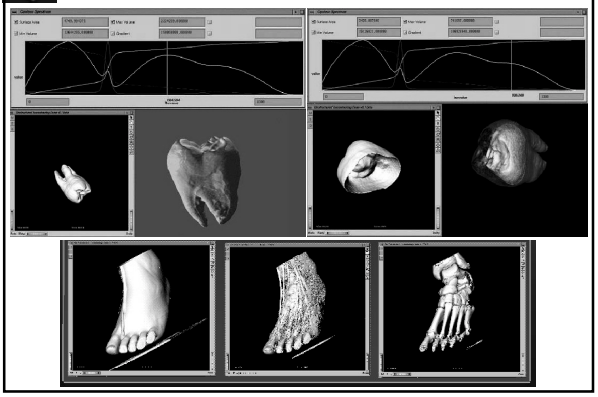
What are the "best" isovalues for extracting the main structures in a volume dataset?

Contour Spectrum (Bajaj, Pascucci, Schikore: Vis '97; Transfer Function Bake-Off: Vis '00)

- Efficient computation of isosurface metrics
  - Area, enclosed volume, gradient surface integral, etc.
- Efficient connected-component topological analysis
- Interface itself concisely summarizes data



Contour Spectrum

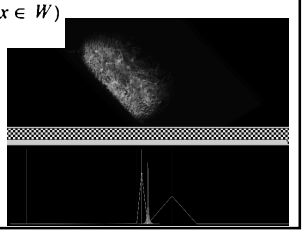


Statistical Signatures

- Localized *k*-order central moments
- At each position *P* in volume, compute …
  - *LM* : mean over local window W
  - m_k: local higher order moment (LHOM)

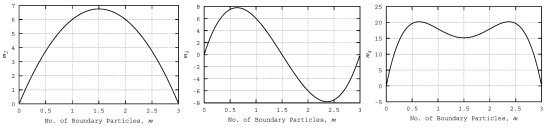
$$m_k = \frac{1}{w}\sum (x - LM)^k \quad ,(\forall x \in W)$$

Example: m_3

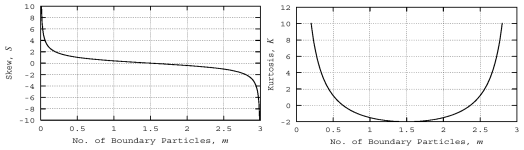


(Thanks to Raghu Machiraju, Shiva Tenginaki, Jinho Lee)

Moments + Cummulants



m_2 m_3 m_4

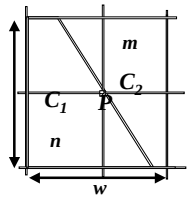


Skew **Kurtosis**

4. Data-Centric

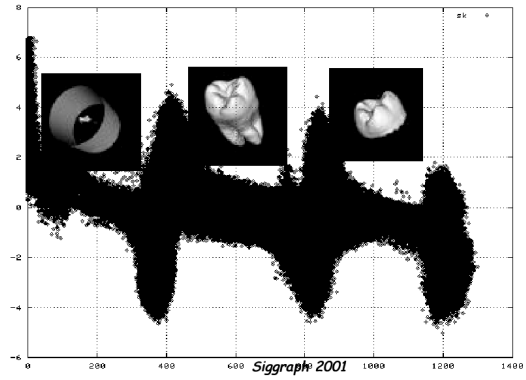
Boundary Model

- Small window
- Boundary if $|C_1 - C_2| > 0$
- Binomial distribution of materials
- Extrema and zero-crossings of moments and cummulants are influenced by presence of boundaries



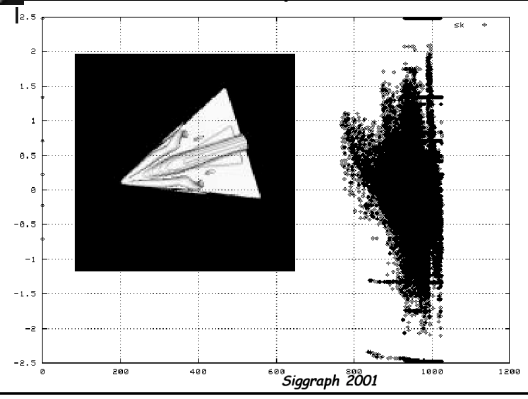
4. Data-Centric

Scatterplots



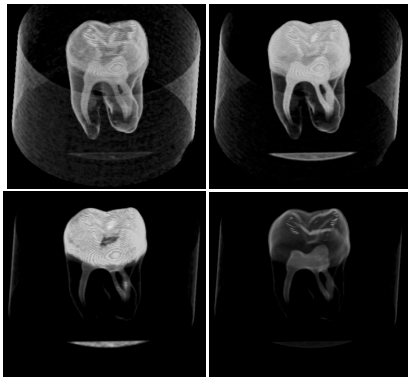
4. Data-Centric

Scatterplots



4. Data-Centric

Tooth renderings



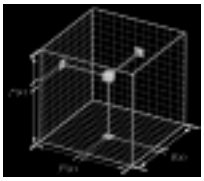
4. Data-Centric

"Semi-Automatic …"

Reasoning:

- TFs are volume-position invariant
- Histograms "project out" position
- Interested in boundaries between materials
- Boundaries characterized by derivatives

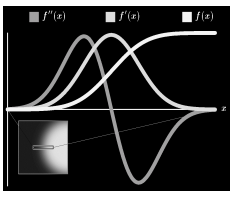
➔ Make 3D histograms of value, 1st, 2nd deriv.

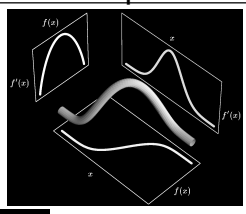


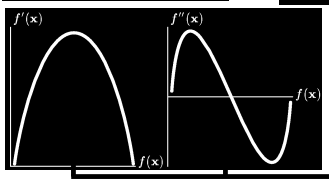
By (1) inspecting and (2) algorithmically analyzing histogram volume, we can create transfer functions

4. Data-Centric

Derivative relationships



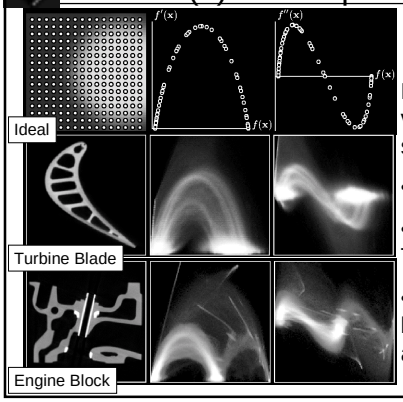




Edges at maximum of 1st derivative or zero-crossing of 2nd

4. Data-Centric

(1) Scatterplots



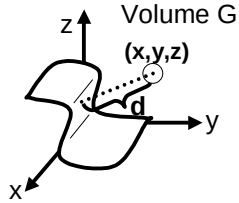
Project histogram volume to 2D scatterplots

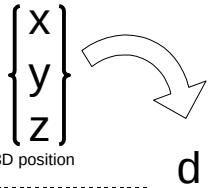
- Visual summary
- Interpreted for TF guidance
- No reliance on boundary model at this stage

4. Data-Centric

(2) Analysis

Volume Graphics Distance Map

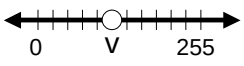




3D position

d — Signed distance to boundary

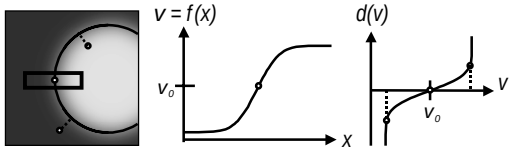
New Distance Map



v — data value

4. Data-Centric

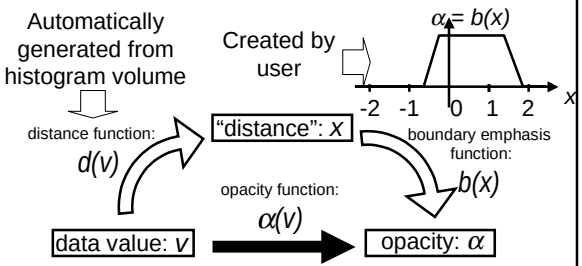
(2) New Distance Maps



- Supports 2D distance map:
  d(v,g); g = gradient magnitude
- Produced automatically from histogram volume via boundary model

4. Data-Centric

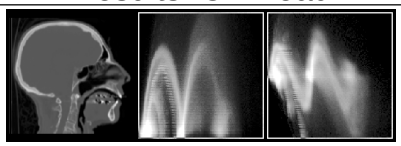
(2) Whole process



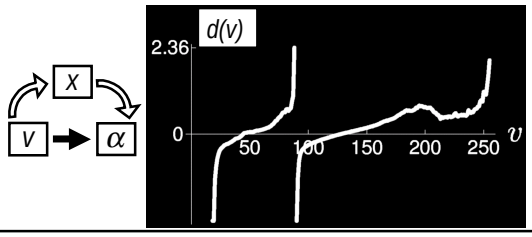
- Opacity function: $\alpha(v) = b(d(v))$
  $\alpha(v,g) = b(d(v,g))$

4. Data-Centric

Results: CT Head

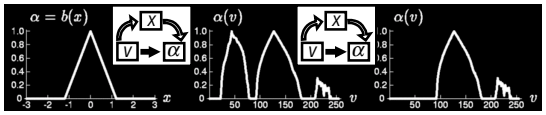


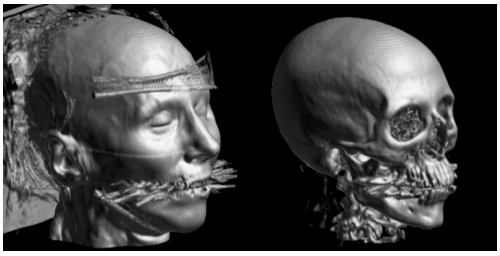
CT head slice f -- f ' f -- f ''



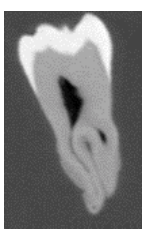
4. Data-Centric

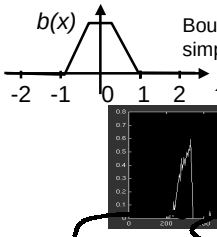
Results: CT Head





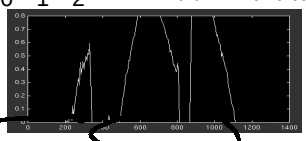
Results: Tooth





Boundary emphasis function simple to set

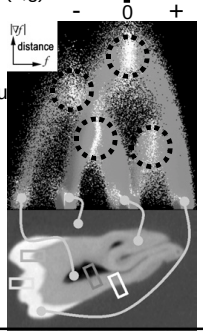
$\alpha(v) = b(d(v))$



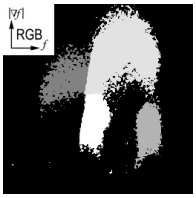
Tooth: 2D transfer function

Detected **4** distinct boundaries between **4** materials

- Pulp
- Backgrou
- Dentine
- Enamel

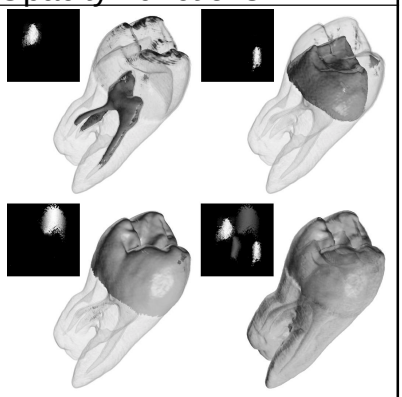


White regions in colormapped 2D distance function plot are boundary centers



Color transfer function

2D Opacity Functions



Accurate isolation of all material boundaries

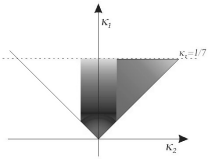
5. Other methods

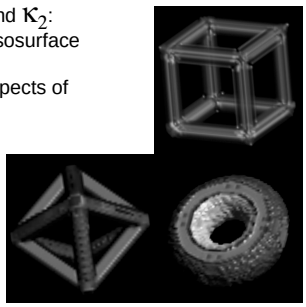
- New domains: curvature
- New kinds of interaction

Curvature

"Curvature-Based Transfer Functions for Direct Volume Rendering", Hladůvka, König, Gröller: SCCG '00)

- Uses 2D space of κ_1 and κ_2: principal curvatures of isosurface at a given point
- Graphically indicates aspects of local shape
- Specification is simple

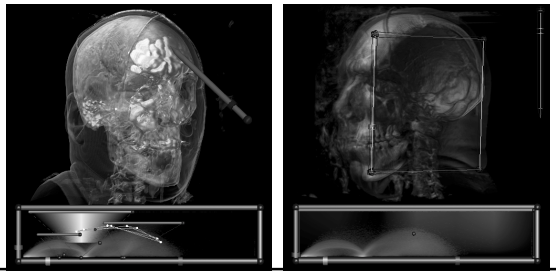




Different Interaction

"Interactive Volume Rendering Using Multi-Dimensional Transfer Functions and Direct Manipulation Widgets" Kniss, Kindlmann, Hansen: Vis '01

- Make things opaque by pointing at them
- Uses 3D transfer functions (value, 1st, 2nd derivative)
- "Paint" into the transfer function domain



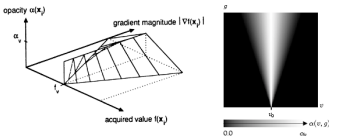
Outline

1. Transfer Functions: what and why
2. Current Methods

3. Ideas for future work

Different domains + ranges

- Time-varying data ("A Study of Transfer Function Generation for Time-Varying Volume Data", Jankun-Kelly, Ma: Volume Graphics '01)
- Multi-dimensional TFs expressive and powerful
  - Leverage current techniques for ease of use
- 2D opacity functions: let's use them!
  - Marc Levoy's 1988 CG+A Paper



- Ranges: Emitance, textures, what else?

Other directions

- Variations on the histogram volume:
  - Different quantities, assumptions, models, analysis?
- Histograms/scatterplots entirely loose spatial information
  - Any way to keep some of it?
  - Can TFs have volume position in domain?

Other directions

- Image-centric methods have a certain appeal
  - Any way to steer and constrain them more effectively?
  - Image-space analysis of TF fitness?
- What kinds of tools do we really want?
  - Analytical vs. expressive, simplifying vs. honest?
  - What is the proper role for human experimentation?